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CHANDRA Discovery of a 300 kpc X-ray Jet in the GPS Quasar PKS 1127-145

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ABSTRACT

We have discovered an X-ray jet with Chandra imaging of the z=1.187 radio-loud quasar PKS 1127-145. In this paper we present the Chandra X-ray data, follow-up VLA observations, and optical imaging using the HST WFPC2. The X-ray jet contains 273±5 net counts in 27 ksec and extends $\sim 30''$ from the quasar core, corresponding to a minimum projected linear size of $\sim 330 h_{50}^{-1}$ kpc. The evaluation of the X-ray emission processes is complicated by the observed offsets between X-ray and radio brightness peaks. We discuss the problems posed by these observations to jet models. In addition, PKS 1127-145 is a Giga-Hertz Peaked Spectrum radio source, a member of the class of radio sources suspected to be young or "frustrated" versions of FRI radio galaxies. However the discovery of an X-ray and radio jet extending well outside the host galaxy of PKS 1127-145 suggests that activity in this and other GPS sources may be long-lived and complex.

Subject headings: Quasars: individual (PKS 1127-145) – galaxies: jets – X-Rays: Galaxies

1. Introduction

The unprecedented sub-arcsecond resolution (Van Speybroeck et al, 1997) of the *Chandra X-ray Observatory* (Weisskopf & O'Dell 1997) gives us, for the first time, the opportunity to study details of the X-ray structures associated with distant galaxies and quasars. Jets observed in Galactic and extragalactic sources are still not well understood and before the *Chandra* launch only a handful of nearby sources were known to have X-ray emission associated with their radio jets (e.g. Harris 2001). *Chandra* has uncovered many X-ray jets with complex structure on arcsec scales (e.g. Marshall et al 2001a,b, Chartas et al 2000, Schwartz et al 2000) in sources up to z=0.6.

PKS 1127-145 is a higher redshift quasar (z=1.187) with a GigaHertz peaked radio spectrum (GPS, Stanghellini et al., 1998), intervening damped Lyman-α (Bergeron & Boisse, 1991) and HI 21-cm absorption, both at redshift z=0.312 (Lane et al., 1998). We observed PKS 1127-145 with the *Chandra* X-ray Observatory, in order to study in detail the quasar X-ray spectrum and the nature of the absorber (Bechtold et al. 2001), but were immediately struck by the presence of a 30″ long, one-sided X-ray jet. At the quasar redshift a 30″ separation implies that the X-ray emitting jet material is at least $\sim 250-330h_{50}^{-1}$ kpc from the central engine which creates the jet. If the jet is not in the plane of the sky the physical distance will be even larger, quite possibly a Megaparsec or more.

The radio spectrum of the core of PKS 1127-145 places it in the GPS class of radio sources (O'Dea 1998) and the extended radio structure in PKS 1127-145 is weak, only ~0.1-0.4% of the core emission (Sec.3.2). This is much less than a typical large scale emission of FRI or FRII galaxies, where the lobes can dominate or be comparable to the core brightness (Kellerman & Owen 1988). Because GPS sources generally show very compact radio morphology (< 1kpc), they have been interpreted as either young counterparts of FRI radio galaxies (Phillips & Mutel 1982), or as "frustrated" AGN (van Breugel 1984, O'Dea 1998), in which the radio jets are not able to penetrate the host galaxy's gas and dust. There are just a few examples of the GPS galaxies with a very faint Mpc scale radio structures (Schoenmakers 1999), which are interpreted as relics of the source past activity. PKS 1127-145 is the first example of a GPS quasar with large scale X-ray emission associated with the faint radio structure.

In this paper we present the *Chandra* X-ray imaging data, as well as the results of our follow-up VLA and HST/WFPC2 observations of PKS 1127-145. We then discuss the jet morphology and possible emission processes, and conclude by considering implications of the large scale X-ray jet on the origin and evolution of GPS sources.

The main results of our observations are (1) the discovery of the large scale X-ray jet in a GPS quasar; (2) improved morphology and frequency coverage of the weak radio jet; and (3) the detection of displacements of the peak brightnesses between the radio and X-ray emission in the knots, such that the X-ray precedes the radio emission moving outward along the jet.

We assume H_0=50 km s^{-1} Mpc^{-1}, q_0=0 throughout the paper, so 1″ corresponds to 11.5 kpc at the quasar redshift.

2. The Observations

2.1. *Chandra* X-ray Data

We observed PKS 1127-145 for 27,358 seconds with the spectroscopic array of the Advanced CCD Imaging Spectrometer (ACIS-S, Garmire et al, in preparation; Weisskopf et al. 1996) on 2000 May 28 (ObsID 866) without any transmission grating in place. The source was located on the back illuminated chip (S3) and offset by $\sim 35''$ from the default aim point position to avoid the node boundary (*Chandra* Proposers' Observatory Guide, POG, 2000). The 1/8 subarray mode with a 0.43 second frame time was chosen to mitigate pile-up, leading to a $1'$x$8'$ image. The X-ray position of the quasar (J2000: 11:30:07.03, -14:49:27.32) agrees with the optical position (Johnston et al 1995) to better than $1''$, as expected given the quality of the *Chandra* aspect solution (Aldcroft et al 2000). We used CIAO (version 2.1; http://asc.harvard.edu/ciao/) software to analyze the data.

A smoothed image of PKS 1127-145 and its associated jet is shown in Figure 1. The intensity has been scaled logarithmically to emphasize the faint jet emission. The small *Chandra* Point Spread Function (PSF), especially the low power in the scattering wings ($r > 1''$), allows for a high dynamic range image, which is essential to the detection of the jet (Figure 1). A total of 16,573 counts was detected in the quasar core, so the total jet emission is ~ 60 times fainter than the core (see Section 3.1.3) and the individual components are as weak as $\sim 1/450$ times the core. The details of the spectral analysis of the central source are reported elsewhere (Bechtold et al. 2001). *Chandra* ACIS-S3 data were reprocessed with the pipeline version R4CU5UPD13.3 on Jan.24, 2001. We have used the reprocessed data and calibration files available in CALDB v.2.1. We note that the aspect uncertainty on the absolute position is less than $\sim 0.5''$ and the uncertainty on the image reconstruction is less than $\sim 0.1''$ (Aldcroft et al 2001). The PSF FWHM at the quasar core is about $0.75''$.

In addition to the standard CXC processing we have corrected the events in the ACIS readout streak (*Chandra* POG, 2000) using the CIAO `acisreadcor` tool assuming a uniform background over the entire chip. This correction moves the events in the readout streak into the core region and does not affect the jet analysis. The corrected image was used only to create a smoothed version of the image. We used the original event file for the analysis of the jet emission and morphology.

We have used the readout streak photons to estimate the pile-up fraction in the data. We have extracted readout streak photons assuming two box regions 4 pixels wide along the streak, excluding the circular region with $6.5''$ radius centered on the core. The count rate in the readout streak is 0.073 cts/frame which gives a pile-up fraction of 2-3% in this observation (*Chandra* POG, 2000).

2.2. VLA Radio Data

At the time of the Chandra discovery of the X-ray jet in PKS 1127-145, the only reported radio detection of the weak kpc jet was that in the thesis of Rusk (1988). Archival VLA data consisted mainly of short observations (PKS1127-145 is a standard VLA calibrator source) and maps from these data did not have sufficient dynamic range to detect the kiloparsec jet. VLBI results for the core have been published by Wehrle et al. (1992) and further monitoring data have been accumulated at 2 cm by Kellermann et al. (http://www.cv.nrao.edu/2cmsurvey/). The Brandeis group has also recently obtained VLBA polarization maps at 8.4 GHz (Homan and Wardle, private communication). All these data show a quasi equal E-W double separated by about 4 mas plus weaker structure in a jet bending off to the NW with a total extent of about 20 mas.

Our new data were obtained at 1.4 and